

C2 Analysis of the Effectiveness of the Coyote LRES D

Eric Dorion

Defence R&D Canada – Valcartier
2459, Pie XI north
Val-Bélair, Québec G3J 1X5
CANADA
[1] 418-844-4000 (4257)
Eric.Dorion@drdc-rddc.gc.ca

Major Michel Gareau

Defence R&D Canada – Valcartier
2459, Pie XI north
Val-Bélair, Québec G3J 1X5
CANADA
[1] 418-844-4000 (4434)
Michel.Gareau@drdc-rddc.gc.ca

ABSTRACT

From October 28th to November 2nd 2001, DREV conducted a joint R&D and military experiment on the effectiveness of the new Lav-Recce Enhanced Surveillance Demonstrator (LRES D). The aim of this experiment was to assess whether Situation Awareness (SA) at the Command Post (CP) level was improved by adding a new suite of sensors on the standard Coyote vehicle, which constitute the enhanced version, namely, the LRES D. The information products produced by both Lav-Recce suites and forwarded to the CP were compared to the ground truth that was carefully designed prior the experiment. The timeliness of these information products is also considered. SA being of the utmost importance to the commander for his C2 duties, it was obvious that this aspect of C2 was to become our prime Measure of Effectiveness (MoE). Measures of Performance (MoPs) that would link both the systems level and the higher MoE were then chosen and strategies to evaluate them identified. This paper describes the experiment and how the experimental protocol was designed according to the principles and guidelines of the NATO Code of Best Practices (COBP) for C2 assessment. It will also clearly demonstrate the Measures of Effectiveness (MoEs) and Measures of Performance (MoPs) that were identified to be the key measures in the context of the experiment, and the considerations over human factors. Finally, the paper will describe the lessons that were learned during the experiment that were not necessarily controlled or expected with the positive and negative aspects that arose from them.

Key Words: Experimentation, Situation Awareness, Measures of Merit, Information Systems.

1.0 INTRODUCTION

Since 1997, numerous research projects have been conducted to improve the actual sensor suite of the Canadian surveillance vehicle called COYOTE. The enhanced version is called the Lav-Recce Enhanced Surveillance Demonstrator (LRES D). A secondary goal to these projects was to validate and test emerging technologies that exploit and help disseminate the information generated by the vehicle suite. The Defence R&D Canada – Valcartier (DRDC Valcartier) held an experiment in November 2001 that aimed at evaluating technological improvements to the Coyote (LRES D) and weigh the capacity to improve Command Post (CP) situation awareness when compared to a standard COYOTE suite.

This document describes the design of the experiment and some of the preliminary results. The NATO Code of Best Practice (COBP) [COBP, 1999] has been used as the general framework for our work. The first

Paper presented at the RTO SAS Symposium on “Analysis of the Military Effectiveness of Future C2 Concepts and Systems”, held at NC3A, The Hague, The Netherlands, 23-25 April 2002, and published in RTO-MP-117.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 00 DEC 2003		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE C2 Analysis of the Effectiveness of the Coyote LRES D				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Defence R&D Canada Valcartier 2459, Pie XI north Val-Bélair, Québec G3J 1X5 CANADA				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADM001657., The original document contains color images.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 10	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

section of the document describes the theoretical background that supports solid and objective experimentation. The second portion deals with the design of the experiment, which is crucial for the identification of strong and weak aspects of the new suite. Also, the design of experiments is a process in which there is much to learn. As we will see, the experimental protocol was designed to reflect the state of the art in applying theoretical models of situation awareness. Whenever possible, quantitative and easy to measure metrics (e.g. system metrics) were preferred over qualitative and hard to interpret ones (e.g., observer notes). In the context of the experiment, measures that were taken in real time had higher priority than the ones that needed to be interpreted after the exercise. During the experiment, the emphasis was put at the vehicle/sensor level to better track and evaluate the passage of raw reconnaissance information up to its next hierarchical command level for further processing and analysis if required. It was hoped that by providing more and improved tools to pre-process and structure reconnaissance information directly at the vehicle level would improve the development of situation awareness at the CP level, therefore reducing redundancy of tasks and optimizing time for analysis and integration into the overall intelligence picture.

2.0 BACKGROUND THEORY

The goal of the LRES-ISTAR experiment, as it is named, was to demonstrate that the new sensor suite better supports the operator in his task of generating information products for higher echelons in the chain of command, in the context of the Canadian ISTAR doctrine. Two quantities describe the information analyst's performance in a precise and complete way: The accuracy of the information he generates for higher echelons, (the Command Post) and the timeliness of his reports. Figure 1 illustrates how the analyst's performance is affected by information accuracy and timeliness. Clearly, region I is the one of high performance while regions II, III and IV are the ones where information products are inaccurate, untimely or worse, both.

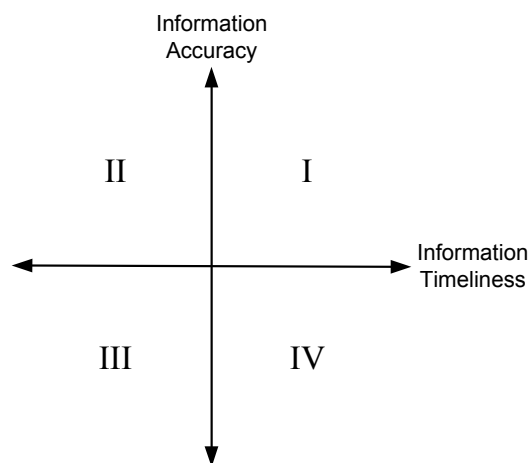


Figure 1: Analyst's Performance.

The experiment should demonstrate how analyst's performance is affected by the addition of the new sensors. Presumably, the performance should be improved, meaning that a point in Figure 1 would move in the general northeast direction. It is therefore important to understand in our context what is information accuracy and timeliness.

Situation Awareness as an MoE

All other things being equal, situation awareness is linked to the information product quality. While situation awareness is intimately linked to what our senses tell us, it is reasonable to think that sensors that extend our own capacities (hearing, viewing, touching, etc.) will help in increasing situation awareness and therefore increasing the information product quality. This reasoning constituted the main driver for LRES-ISTAR experiment. Since, situation awareness as our prime Measure of Effectiveness (MoE) is the key element to determine the information product quality, it is important to well understand how it is defined and how it is influenced. According to Endsley [Endsley, 1988], situation awareness is the perception of the elements in the environment, within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future. Figure 2 illustrates this definition.

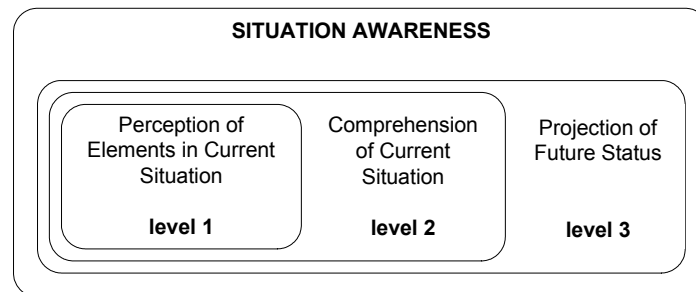


Figure 2: Situation Awareness.

In the context of the LRES-ISTAR experiment, we were interested in determining whether bringing the new sensor suite would increase or not the operator's situation awareness. We argued that assessing level 1 of Endsley's situation awareness model would suffice for the task. We did not concentrate ourselves on level 2 and level 3, since the introduction of new sensors would not influence them. Furthermore, Jones and Endsley [Jones and Endsley, 1996] report that 76% of errors attributed to situation awareness of fighter pilots come from problems at level 1 of the model. This emphasizes the importance of perception in Endsley's model. It is important to note also that the model considers temporal aspects like elements that influence situation awareness. However, these aspects have their influence mostly on level 2 and 3 of the model and therefore are of less relevance to our case. Of course, temporal aspects were of prime importance to our experiment, but not in the sense Endsley defined them. We capture temporal aspects in the concept of timeliness as discussed above and in the next section.

Timeliness of Information

All other things being equal, the analyst's performance depends on the timeliness of his reports. Figure 3 demonstrates the concept of timeliness and 3 particular cases. Figure 3(a) shows the general case where information is useless before τ_1 , useful for a $\tau_2 - \tau_1$ period, and finally too old after τ_2 (e.g., daily reports on refugees' situation). Figure 3(b) shows the case where information is highly pertinent but for a very short period of time (e.g., imminent bombing raid) and Figure 3(c) shows the case where information stays pertinent at all times (e.g., casualty reports). The analyst's performance is linked to his capacity of generating and forwarding information that is timely, meaning that his reports always fall under the timeliness curve of Figure 3. Whether this is an easy or difficult task depends on the shape of the curve.

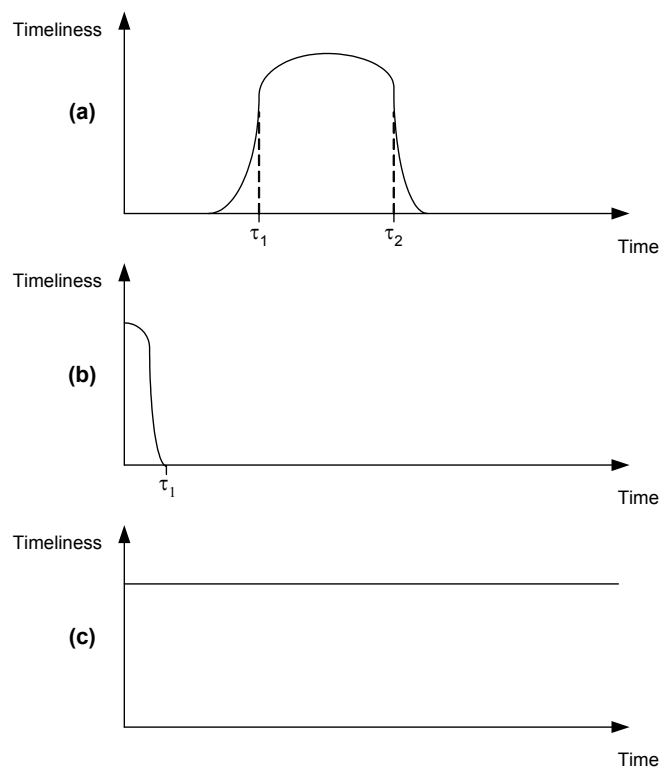


Figure 3: Examples of Information Timeliness.

While the concept of timeliness is easy to grasp, choosing metrics that will measure it adequately is rather difficult.

3.0 LINKING OUR MoE WITH MoPs

The NATO Code of Best Practice states that linking high-level metrics to system-level ones (MoEs-to-MoPs) is very challenging. We fully concur with this point. However, it is the only way by which one can achieve valuable C2 assessment. This section deals with the identification of 2 Measures of Performance (MoPs) and their linking to our prime MoE.

All measures in the context of the LRES-ISTAR experiment must be taken with respect to the evaluation objectives that were stated in section 2. This also is consistent with the NATO COBP guidelines. It is therefore of prime importance to assess the analyst's accuracy of perception since it is a determining aspect of the information product's quality. The timeliness of this product has to be determined as the second parameter to the information product's quality.

In order to evaluate the analyst's quality of perception and the timeliness of the information product, we literally have to build the right instruments to measure them. We also have to choose carefully where these probes will be placed in the system. We need therefore to understand the nature of the observables which are the standard Coyote and the LRES Coyote.

Description of the Coyote Vehicles

In essence, the Coyotes are surveillance vehicles equipped with a certain number of sensors that extend the perception's capacity of a human. Table 1 enumerates the sensors for both vehicles.

Table 1: Coyotes' Sensor Suites

Standard Coyote	LRES
<ul style="list-style-type: none"> Visible spectrum camera Passive infrared camera Radar 	<ul style="list-style-type: none"> Visible spectrum camera Passive infrared camera Radar Active infrared camera Acoustic sensor array Coyote Battle Management System (CBMS)

In addition to its extended suite of sensors, the LRES has a rudimentary information system that helps fusing information that comes from the sensors. This system is called "CBMS" (Coyote Battlefield Management System). It consists of a screen that centralizes sensor information, so it allows the analyst to focus on one screen instead of many. CBMS provides tools to manipulate and adjust the sensors of the LRES and display their information on a map-based interface. It also allows the refinement and description of reconnaissance information items. Attachments such as video, annotated photos/imagery or even text documents can also be linked to the information items, thus enriching its "situation awareness value" for the next analyst.

Both Coyotes have means to disseminate information to upper levels in the chain of command (CP). Table 2 resumes these capacities.

Table 2: Coyotes' Information Dissemination Facilities

Standard Coyote	LRES
<ul style="list-style-type: none"> Paper reports (preformatted) Voice radio link Video recording Structured messaging via TCCCS-IRIS 	<ul style="list-style-type: none"> Paper reports (preformatted) Voice radio link Video recording Structured messaging via TCCCS-IRIS High-bandwidth uplink to the CP via NTDR radios (full TCP/IP).

C2 Analysis of the Effectiveness of the Coyote LRES D

Communication links from the Coyotes to their respective CPs are shown in Figure 4. Both vehicles can transmit information by voice and data through the digital radio system “TCCCS-IRIS”. However, transmitting data through TCCCS-IRIS requires the preparation of formatted messages in USMTF format mainly. We recall that in the context of this experiment, we do not want to focus on the treatment of information but rather on its detection (perception). For this reason, we denied the use of data transmission through TCCCS-IRIS, leaving the standard Coyote with voice transmission only. The LRES D is equipped with an NTDR radio that basically gives full TCP/IP capabilities over a 287 kb/s channel. At this rate, it is reasonable to transmit short videos and particularly overlays to the All-Source Intelligence Producer (ASIP). ASIP is a command and control information workbench prototype that supports the intelligence operator in his task. Basically, the information produced by the LRES D was sent over the NTDR link and reproduced on an ASIP overlay in the CP.

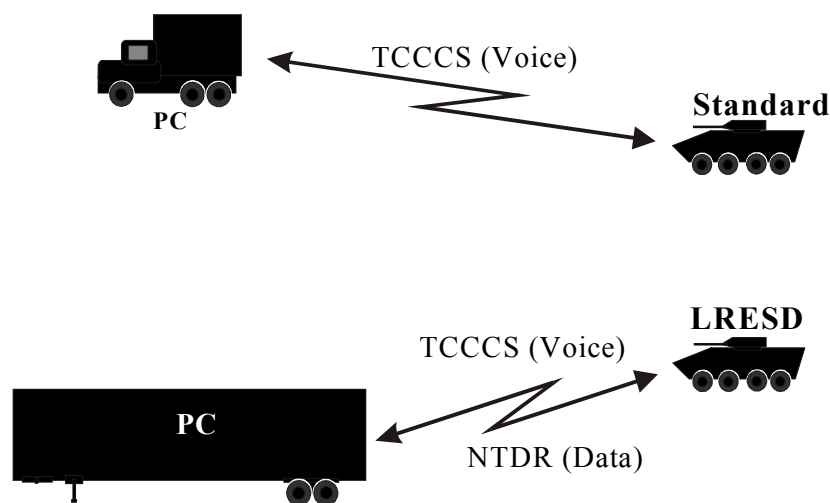


Figure 4: Communications Links.

Although the communications links of the 2 configurations are different (voice vs. data) and that the receiving ends (ASIP vs. CP analyst) are different also, there is no impact on our experiment because we chose to record the state of the information at the moment where the information products quit the vehicles and not the moment they arrive at the CP (or later). In fact, the use of ASIP fulfilled other goals that were of no relevance to this experiment. On the other hand, the information products quality was determined by a judge afterwards.

Coyotes Deployment

In order to verify the impact the new sensors and CBMS have on the analyst’s situation awareness, it is important that all other parameters that might influence it be kept constant. One of these parameters is the position of the vehicles. Both vehicles were given the same zone of surveillance. Within this zone, events that would elicit responses from different sensors occurred. Although the vehicles were apart (about 100 feet), their sensor suites were collocated, giving equal chances of detection. Of course, the nature of certain events would not trigger equally both sensor suites, and that’s the point of making the experiment. This is the case notably for acoustic events, which are only detectable through the acoustic array of the LRES D. Sensor detection does not necessarily mean human detection and it might occur that certain acoustic events would not be detected (and reported) by the intelligence analyst. The point was to find why. Of all the hard

data that we obtained from this experiment, notes from passive observers were probably the most important source of discovery for improving our systems. We discovered hidden aspects of the system that had significant impact on the way information flow was influenced. Some of these aspects were good (e.g., inferring information from the toggling between 2 sensors), others were bad (e.g., overloading the analyst's job).

4.0 SYSTEM-LEVEL METRICS (MoPs)

The Coyotes and their information analysts constitute systems that accept inputs (sensor information) and give outputs (information product). In a simplified way, an output $y(t)$ is a representation of the input with a certain scaling factor, and delayed by a certain period of time. So,

$$y(t) = a \cdot x(t - \tau)$$

Distortion Factor a

The scaling factor a represents the situation's quality of perception of the system (sensor suite + intelligence analyst). This distortion, which may be non-linear, depends on the quality of the sensor-analyst set. By setting the analyst's competence to a constant, the distortion factor a depends on the sensor suite quality. With a series of identical events presented to both Coyote vehicles, we obtained a direct measure of the quality of perception and therefore a measure of the gain in situation awareness. This measure depended on the sensor suites. In practice, this factor is evaluated in the CP by a judge as a function of the difference between the information reported and the ground truth. The distortion factor is evaluated along these guidelines:

- Object detected or not
- Correct identification of the object
- Accuracy of the reported position of the object
- Estimated object speed
- Assessed activity of the object
- Projected behavior of the object

Delay Factor τ

The delay factor τ is defined as the elapsed time between the moment where an event occurs and the moment where this event is actually reported to the CP by the information analyst. It is equal to the sum of the delay of sensor detection (τ_c), the delay of analyst detection (τ_d), and the delay of analyst information processing (τ_p). So,

$$\tau = \tau_c + \tau_d + \tau_p$$

We supposed that information would not be intentionally retained by analyst for over-processing. Also, we judged that sensor detection delays would be negligible when compared to the analyst detection and information processing delay. τ is influenced by several factors like the analyst's attention, sensors ergonomics, information ambiguities, information overloading, etc. It is important to understand that this delay is normal and that it only gains significance when compared to the timeliness profile of this

C2 Analysis of the Effectiveness of the Coyote LRES D

event. For example, a delay τ situated between τ_1 and τ_2 in Figure 3(a) is perfectly acceptable, while a delay τ longer τ_1 than in Figure 3(b) is alarming. Timeliness profiles for each event (or group of events) were to be known prior the experiment in order to evaluate the analysts' performance against temporal aspects.

Practical Considerations

While α and τ were measurable by introducing probes at the right places in the system, we preferred using passive educated observers as the main measuring instruments for this experiment. "Passive" observers are non-intrusive agents. They do not interfere with the analyst's job, they do not help nor do they comment the analyst's behaviour. This is important since it would introduce significant distortion in both temporal and quality metrics. "Educated" observers know what events will occur, when they will occur. This prior knowledge enables them to focus their observations to what is important to note and therefore explain why certain delays are particularly long (e.g. an analyst distracted by something).

Someone might say that using humans as observers may introduce subjectivity to the outcome of the experiment. We argue that certain aspects of systems (including human-in-the-loop) are simply not possible to evaluate without observers. Two aspects of using observers must be avoided at all costs. The first is an observer with unclear objectives. He will observe things all right, but without any focus on the assessment objectives, the observations become useless. The second one is an observer in a mechanized role. By knowing the nature of the measures he takes, an observer can comment aspects of his measures, enabling statistical analysis after the experiment. If not, numbers will be numbers and some won't be explainable.

5.0 SUMMARY

While the data obtained in the three-day experiment is still being analyzed and that we cannot present fancy graphics yet, we still can talk about the lessons learned. First, we noted that the degree of integration of CBMS, the LRES D information system, was not sufficient to support efficiently the analyst's task in the vehicle. Indeed, the analyst had to jump from a sensor to another in order to acquire enough information and this lead to increased delays in the processing. Second, we noticed that sensor sweeping counted for a fair portion in the delay of detection, especially at nights. Fortunately, we were able to evaluate these delays enough for compensation. Third, the acoustic array is a sensor suite that triggers the interest of the analyst. At best, it gives the bearing and range of a certain target. The analyst must then rely on the other sensors to effectively confirm and identify the target. While this new sensor may help greatly the analyst by focusing his attention, the benefit of having an acoustic array may not have been measured with the metrics we chose. In fact, we feel that we did not measure it well. Empirically, our results show no benefit of having this type of sensor, but this is not because there is no benefit of having it. It was merely a question of choosing the right metrics. Fourth, there are events that are intrinsically hard to detect. Snipers on observation mission are one example. In this case, a reconnaissance vehicle is almost lucky to detect one even with the LRES D extended sensor suite. This inserted great distortions in our results. Fifth, giving new tools to the analyst has a non-negligible impact on the standard operating procedures (SOPs). New sensors mean new ways of interpreting information and therefore new ways of doing things. The analyst's job is impacted and parameters that should have stayed constant throughout the experiment might have varied without us knowing.

These are but a few things that we learned in this experiment. The application of the experiment protocol was a complex task given the many parameters and uncertainties typical to military operations. The NATO COBP helped us designing the protocol, particularly concerning the choice of metrics. Conducting experiments is a

process that one can only learn through experience. It left us with many valuable lessons. We hope to have transmitted some of these to the reader.

6.0 REFERENCES

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7.0 LIST OF ACRONYMS

ASIP	All-Source Intelligence Producer
C2	Command and Control
CBMS	Coyote Battlefield Management System
COBP	Code of Best Practice
CP	Command Post
DREV	Defence Research Establishment Valcartier
ISTAR	Intelligence Surveillance Target Acquisition and Reconnaissance
LRES	Lav-Recce Enhanced Surveillance Demonstrator
MoE	Measure of Effectiveness
MoP	Measure of Performance

AUTHOR BIOGRAPHY

Eric Dorion is a computer scientist in the Metrics and Experimentation group (System of Systems section) at the Defence R&D Canada – Valcartier. He was the scientific authority of the LRES-ISTAR experimental protocol. He is currently doing his master’s degree on the performance of military distributed information systems. He is also doing a master’s degree in business and administration (MBA) with a specialization in management information systems.

Major Michel Gareau is the land liaison officer in the System of Systems section at the Defence R&D Canada – Valcartier. He was the military leader of the LRES-ISTAR experiment and is the military leader on many other similar projects, notably ASIP.

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